Evaluation of Malathion, Synergized Pyrethrum, and Diatomaceous Earth as Wheat Protectants

. . . In Small Bins

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This report presents results of tests with several materials applied to wheat as protectants against insect attack. Malathion at two dosage rates, synergized pyrethrum, and a diatomaceous earth were tested. This work is a part of a broad program of research to improve the quality of food that reaches the consumer by preventing damage in marketing channels.

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The work was done at the Manhattan, Kans., station of the Stored-Product Insects Research Branch, Market Quality Research Division, Agricultural Research Service, U.S. Department of Agriculture. J. L. Wilson, Ralph L. Ernst, Warren Blodgett, and Leon H. Hendricks, biological aides, assisted in the work. All of the residue determinations were made by the Chemical Unit at the Stored-Product Insects Laboratory at Savannah, Ga.

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The lesser grain borer, *Rhyzopertha dominica* (Fabricius) was not included as a test species in this study. Strong and Sbur[1] state that "increases in total numbers of the lesser grain borer in seeds (wheat) treated with the equivalent of four pounds of diatomaceous earth per ton (120 pounds per 1,000 bushels) were considerably greater than in the untreated. . . . Only the eight pounds-per-ton treatment appeared to be effective against the lesser grain borer for periods longer than nine months." This information will be of considerable importance in the treatment of wheat known to be infested with this species.

[1] Strong, R. G., and D. E. Sbur. protection of wheat seed with diatomaceous earth. Jour. Econ. Ent. 56 (3): 372–374. 1963.

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Evaluation of Malathion, Synergized Pyrethrum, and Diatomaceous Earth as Wheat Protectants . . . In Small Bins

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SUMMARY

Malathion at two dosage rates, synergized pyrethrum, and a diatomaceous earth were applied to hard red winter wheat as protectants against insect attack in small bins.

Insects readily developed in untreated wheat (check) during the first 3 months after treatment. Damaging infestations became firmly established during the 12-month test period in all wheat except that treated with 1.5 pints of premium-grade malathion emulsifiable concentrate per 1,000 bushels.

The 1.5-pint dosage of malathion gave nearly complete protection from insect damage for 12 months. The 1.0-pint dosage of malathion was less effective. Insects did not specifically prefer or avoid malathion-treated wheat in food selection studies.

Synergized pyrethrum gave slightly less overall protection than did the diatomaceous earth. It maintained a high degree of repellency throughout the test period, yet large populations of insects developed. The piperonyl butoxide residues degraded erratically during the first few samplings but apparently stabilized after 6 months.

Fewer external forms of insects were found in samples treated with diatomaceous earth at the end of the test period, but internal infestation was almost five times as much as in the 1.5-pint malathion treatment. The diatomaceous earth and the synergized pyrethrum were about equally repellant to the insects, but neither protected wheat as well as malathion at either dosage. The diatomaceous earth drastically reduced the test weight of the grain.

BACKGROUND AND OBJECTIVES

The primary objective of this study was to compare the effectiveness of malathion and synergized pyrethrum emulsions and a diatomaceous earth dust as wheat protectants in small bins—a method that is intermediate between large field-scale applications and small jar tests in the laboratory.

Field-scale, large-bin tests are expensive, time consuming, and restricted in the number of variables and replications that can be included. Jar tests are necessarily limited in scope and not representative of conditions under which treatments are applied commercially. Five-cubic-foot cylindrical bins have been used successfully in extensive intermediate-type storage studies with corn[2,3] and with farmers stock peanuts.[4] Exploring dosage rates and residue degradation in small-bin tests of materials that show promise in jar tests should result in an evaluation of protectant materials at a considerable savings in time and cost. After the small-bin, intermediate-type study, only the most promising insecticidal materials would be field tested with selected dosages in large-scale experiments.

MATERIALS AND METHODS

The experiment was begun in May 1961. Uncleaned hard red winter wheat, purchased locally during the 1960 harvest, was stored in a metal bin for 9 months before testing.

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[2] LA HUE, D. W., HERBERT WOMACK, and B. W. CLEMENTS, JR. TREATMENTS FOR THE PROTECTION OF STORED SOUTHERN-GROWN CORN FROM RICE WEEVIL ATTACK—EXPLORATORY TESTS. U.S. Dept. Agr. Market. Res. Rpt. 272, 22 pp. 1958.

[3] LA HUE, D. W. SMALL-BIN EVALUATION OF MALATHION, SYNERGIZED PYRETHRUM, AND DIATOMACEOUS EARTH AS SHELLED CORN PROTECTANTS. (Talk given at Annual Meeting of the Entomological Society of America, at St. Louis, Mo., Dec. 2–5, 1963).

[4] LA HUE, D. W., B. W. CLEMENTS, JR., and HERBERT WOMACK. IN-STORAGE TREATMENTS FOR THE PROTECTION OF FARMERS STOCK PEANUTS FROM INSECT DAMAGE—EXPLORATORY TESTS. U.S. Dept. Agr. Market. Res. Rpt. 363, 32 pp. 1959.

Emulsion sprays prepared from premium-grade 57-percent malathion emulsifiable concentrate were applied to 20-bushel lots of wheat at both the recommended dosage of 1.0 pint per 1,000 bushels (10.42 p.p.m.) and also at 1.5 pints (15.62 p.p.m.). A piperonyl butoxide-pyrethrins emulsifiable concentrate (Pyrenone® 60-6 O.T.) was used at the rate of 1 quart per 1,000 bushels (21.4 and 2.14 p.p.m.). Neutral distilled water was used in formulating the sprays for application by a Mist-O-Matic Seed Treater, which was adjusted to apply 5 gallons of finished spray per 1,000 bushels of wheat. An excess of spray material was prepared to allow for proper agitation and application.

The diatomaceous earth (Perma Guard®) was thoroughly mixed with the wheat by rotating them in a barrel roller for 5 minutes. On instruction from the manufacturer, the dosage applied was to be at the rate of 4 pounds per ton. The actual amount used in the tests was at the rate of 25 pounds per 1,000 bushels, or 4.17 pounds per ton. The present (June 1965) label recommendation is 7 pounds per ton.

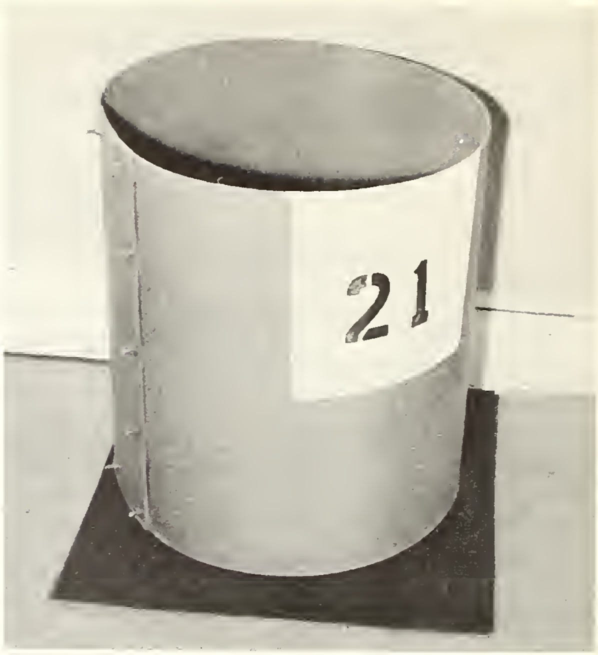

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FIGURE 1.—One of the small bins used in testing insecticides applied to wheat as protectants against insect attack.

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FIGURE 2.—Bins in infestation room before they were filled with wheat for testing insecticides.

Immediately after the individual treatments, about 4 bushels of the treated grain was placed in each of the small bins. These bins, shaped like upright cylinders, held 5 cubic feet each (fig. 1). Each was set on a 2-foot-square sheet of building felt over a masonite base. Five replicates of each treatment, with five check bins, were placed in a 5 x 5 block arrangement in a 13- by 18-foot room on the first floor of a heated dwelling house (fig. 2).

The temperature in the infestation room ranged from 67° to 97° F. in the summer and from 51° to 93° in the winter. Humidity was not controlled and varied greatly throughout most of the storage period. During the summer humidity ranged from 28 to 97 percent, paralleling the atmospheric changes. It was exceptionally low during the cold winter period, ranging from 20 to 40 percent when the forced-air circulating, gas-fired furnace was in operation.

Rice weevils (*Sitophilus oryzae* (Linnaeus)), confused flour beetles (*Tribolium confusum* Jacquelin du Val), red flour beetles (*Tribolium castaneum* (Herbst)), flat grain beetles (*Cryptolestes pusillus* (Schönherr)), and saw-toothed grain beetles (*Oryzaephilus surinamensis* (Linnaeus)) were reared on wheat, corn, sorghum, and special culture nutriments for release in the infestation room. Five thousand or more of these insects were scattered in the aisles and around the bins 14, 33, 59, 126, and 198 days after the experiment was started.

SAMPLING

Replicated composite samples of each treatment variation were taken as the treated wheat fell from the seed treater. Later, after the wheat had been divided into replicates and placed in the bins, other samples of the same size were taken from each bin as the surfaces were leveled. These samples were left undisturbed in open 1-gallon, large-mouthed glass jars in the infestation room and continuously exposed to mixed populations of insects. These samples were used to estimate, by a visible assessment of damage, the effect of the initial handling procedures and of the subsequent molestation of the bins by the periodic probings. Other composite samples were taken from each bin for initial determinations of moisture content, weight per bushel, and chemical residues.

Seven days after the storage test was begun, and at 1, 3, 6, 9, and 12 months after that time, samples of grain were taken with a nonpartitioned grain trier or probe. The probe was inserted twice near the center of each bin and once about 2 inches from the bin wall at each of the four major directions—for a total of 6 samples. The insects were screened out soon after probing. The dust from samples containing the diatomaceous earth was screened with a fine mesh sifter and returned to the samples from which it had been removed. The live insects were counted for an estimate of the populations in the various bins.

Replicated 125-gram subsamples of these probe samples were placed in ½-pint cardboard cartons to be used for the toxicity or bioassay tests. Other replicated 125-gram subsamples from all bins of each treatment were placed in food preference or selection chambers to determine the repellency or attractiveness of wheat treated with these insecticidal materials when the insects had a choice of all treatments. Later, after the bioassay and food preference tests had been completed and all adult insects had been removed, the subsample replicates from each bin were combined and stored in screen-covered 1-quart jars to provide an estimate of damage by the progeny of the insects involved.

The remainder of the wheat from the probe samples was briefly stored in sealed, 1-gallon jars until used to determine the moisture content, weight per bushel, and insecticidal residues persisting at the various intervals of storage.

Each time a major introduction of insects was made in the infestation room, the insects were observed for a period of time to see which bins they entered and in what parts of the room they were most numerous. The appearance of dust around the base of each bin was recorded as an indication of general insect activity in that bin.

At the end of the 12-month test period, as the individual bins were emptied, two duplicate 1-gallon samples were collected progressively from top to bottom. These samples were first screened to remove insects, kernel bits, and frass. Then, by sifting over a No. 18 sieve, the kernel bits and insects were separated from the frass, which was used to estimate the extent of insect damage in the wheat. The wheat was retained for 60 days to obtain records of insect emergence.

At the end of the tests, five replicated, 100-kernel samples from each bin were examined to determine the percentage of kernels damaged by insects and the percentage of kernel weight loss due to insect feeding.

RESULTS

A marked reduction in moisture content occurred in bin samples during the 6- to 9-month storage interval, which reflects the low relative humidity in the infestation room during this period (table 1). During January, after 8 months of storage, the maximum and minimum relative humidity recorded at bin-top level in the storage room was 27 and 20 percent, respectively. As the relative humidity increased during the warm spring months, the moisture content in the samples from the bins increased.

Insecticide Residues

Initial residue recoveries of 9.2 and 15.5 parts per million (p.p.m.), respectively, from the 1.0- and 1.5-pint applications of malathion were considered rather high; however, the results from the different bins were remarkably uniform. The malathion residues degraded in a uniform pattern (table 2).

From the determinations made of the piperonyl butoxide residues, the residual pyrethrins

TABLE 1.—*Moisture content of wheat at various intervals after insecticide treatment*

Insecticide and dosage per 1,000 bushels	Moisture content—						
	Before treatment	After 7 days	After 1 month	After 3 months	After 6 months	After 9 months	After 12 months
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Malathion:							
1.0 pint	11.33	11.48	11.82	12.52	11.16	9.67	11.65
1.5 pints	11.35	11.42	11.81	12.50	11.25	9.57	11.64
Synergized pyrethrum: 1.0 quart	11.43	11.56	11.89	12.59	11.20	9.80	11.58
Diatomaceous earth: 125 pounds	10.83	10.50	11.33	11.89	10.83	9.16	11.38
Untreated check	11.17	11.43	11.76	12.46	12.23	11.18	12.99

TABLE 2.—*Residues on wheat at various intervals after insecticide treatment*

Insecticide and intended dosage	Calculated application	Residues recovered by chemical analysis[1]—					
		Before treatment	After 1 month	After 3 months	After 6 months	After 9 months	After 12 months
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
Malathion:							
10.42 p.p.m.	11.0	9.2	5.4	3.9	3.5	2.9	2.5
15.62 p.p.m.	16.7	15.5	14.2	4.2	5.7	4.9	3.7
Synergized pyrethrum:[2] 21.4–2.14 p.p.m.	22.4	6.6	10.7	12.9	8.4	8.8	9.9

[1] Values are expressed in parts per million of the insecticide, based on actual weight of the wheat.

[2] Analyses were made for piperonyl butoxide, and it is assumed that recoveries can be used to estimate the residues of pyrethrins at a 10 to 1 ratio.

were estimated by assuming that the residues of the pyrethrins and those of the piperonyl butoxide were in the same proportion as in the original formulation. The piperonyl butoxide residues degraded in an erratic pattern during the first few samplings but apparently stabilized after 6 months.

Insect Populations

Most of the insects crawling about in the infestation room were fairly uniformly distributed on the floor rather than on the walls or ceilings. The amount of insect excrement and other dusts around the bases of the bins varied according to the active insect populations within the bins. A little dust was found during the latter part of the test period around bins treated with the 1.0-pint dosage of malathion. Practically no dust was found around the bins with the 1.5-pint application. All of the bins containing untreated wheat and wheat treated with the synergized pyrethrum had traces or small amounts of dust around the bases after 3 months, and the amounts gradually increased throughout the test period.

The numbers of live adult insects recovered from probe samples from all bins at specified intervals (table 3) indicate the populations within the bins throughout the test period. After 1 month, healthy mixed populations were found in all untreated check bins, but comparatively few live insects were recovered from samples of other bins. After 3 months, tremendous populations were found in untreated check bins, considerable numbers were found in those treated with synergized pyrethrum and the diatomaceous earth, and smaller numbers in the malathion-treated bins. The low humidity of the heated air that circulated in the infestation room during the winter months before the 6-month sampling and continued until after the 9-month sampling reduced the moisture content of the grain and possibly was responsible for the lower counts of insect populations within all of the bins at the 9-month period. The probe counts alone show comparable results for the 1.5-pint dosage of malathion and the diatomaceous earth at the end of the test period.

For the first 9 months, the amount of dust around the bases of bins containing wheat treated with the diatomaceous earth was not great and compared favorably with the amount around bins with the 1.0-pint application of malathion. The dust around the former bins during the last months of the test period steadily increased to exceed that around bins of wheat treated with 1.0-pint application of malathion but remained far less than the amount noted around bins of wheat treated with synergized pyrethrum.

The numbers of insects seen entering the wheat in the various bins, during 30-minute observation periods within 6 hours after major introductions of insects to the infestation room, are given in table 4. Comparatively few insects were seen to enter the bins of wheat treated with the synergized pyrethrum and diatomaceous earth, although the numbers increased slightly and gradually as the test period continued. Insects entered the malathion-treated and untreated check bins readily.

TABLE 3.—*Live adult insects in all probe samples of insecticide-treated wheat taken during the 12-month test period*

Insecticide and dosage per 1,000 bushels	Insects in samples taken after— 1 month	3 months	6 months	9 months	12 months	Total
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Malathion:						
1.0 pint	7	146	549	149	722	1,573
1.5 pints	5	94	254	65	317	735
Synergized pyrethrum: 1.0 quart	27	1,127	1,062	291	1,909	4,416
Diatomaceous earth:						
125 pounds	52	460	69	33	303	917
Untreated check	868	7,785	9,099	8,693	9,469	35,914

TABLE 4.—*Insects entering bins of wheat at various intervals after insecticide treatment during 30-minute observation periods following major insect releases*

Insecticide and dosage per 1,000 bushels	Insects entering wheat after interval of— 33 days		59 days		126 days		198 days	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Malathion:								
1.0 pint	369	29.50	550	26.57	539	29.31	589	30.13
1.5 pints	442	35.33	637	31.23	476	25.88	561	28.70
Synergized pyrethrum:								
1.0 quart	33	2.64	45	2.17	59	3.21	99	5.06
Diatomaceous earth:								
125 pounds	48	3.84	75	3.61	102	5.55	165	8.44
Untreated check	359	28.70	763	36.86	663	36.05	541	27.67
Total observed	1,251	----	2,070	----	1,839	----	1,955	----

Food Selection Studies

As a more direct test of acceptance by the insects or of repellency and attractiveness of the wheat protected by the various treatments, about 250 rice weevils were released in food preference or selection chambers. In this apparatus (fig. 3), five cartons, each containing a 125-gram subsample of wheat from one of the different treatments, were exposed to a dispersal of insects released in the center depression. The insects were allowed 24 hours to disperse to any one of the cartons containing an acceptable or preferred food. From 94.5 to 100 percent of the rice weevils responded, in the many test offerings, by entering the cartons. In these multichoice tests, both synergized pyrethrum and the diatomaceous earth treatments seemed to make wheat distinctly undesirable as food for the rice weevils; considerably fewer entered the wheat treated with either than entered the untreated wheat (table 5). This avoidance was noted throughout the test period. The fact that the synergized pyrethrum exhibited this action after 12 months' aging is a confirmation of the stability level shown in the recovery of the piperonyl butoxide residues.

Malathion definitely did not repel the rice weevils.

Results of these preference studies correlated well with the observations of the insects entering the bins (table 5).

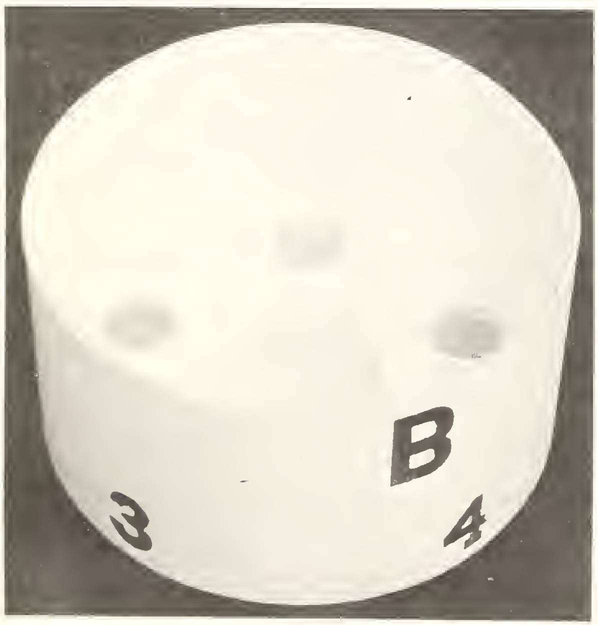

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FIGURE 3.—Food preference chamber used in testing insecticide-treated wheat.

Toxicity Studies

Replicated 125-gram subsamples of the probe samples were used for the toxicity tests. About 50 insects (either rice weevils or confused flour beetles) were put into each of the ½-pint cardboard cartons of wheat, which were stored in the same room with the bins. Mortality readings were made 7 and 14 days later. Seven days and also 1 month after the insecticides were applied, malathion, synergized pyrethrum, and

TABLE 5.—*Response of rice weevils to insecticide-treated wheat in food preference studies*

Insecticide and dosage per 1,000 bushels	Weevils that entered wheat during a sampling period of—				
	7 days	1 month	6 months	9 months	12 months
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Malathion:					
1.0 pint	31.83	30.97	26.33	27.42	29.70
1.5 pints	38.86	36.79	28.42	33.42	28.74
Synergized pyrethrum:					
1.0 quart	6.86	4.18	8.78	3.87	8.85
Diatomaceous earth:					
125 pounds	1.65	3.72	5.39	1.63	10.81
Untreated check	20.98	24.37	31.02	33.71	21.87

the diatomaceous earth were completely effective against rice weevil adults (table 6). Malathion at both dosages continued to be effective against rice weevils even 12 months after it had been applied to the wheat.

The synergized pyrethrum lost its effectiveness against the rice weevil after the 1-month period.

The diatomaceous earth became somewhat progressively less effective after the first month, but the killing action shown in the 14-day readings was much greater than in the 7-day readings. Malathion showed a more rapid killing action.

Malathion at both dosages was effective for 1 month against the adult confused flour beetles,

TABLE 6.—RICE WEEVIL ADULTS: *Mortality after exposure of 7 and 14 days to samples of insecticide-treated wheat*

Exposure period, insecticide, and dosage per 1,000 bushels	Mortality during sampling period of—					
	7 days	1 month	3 months	6 months	9 months	12 months
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
7 days:						
Malathion:						
1.0 pint	99.8	100.0	99.0	92.5	[1]99.5	76.6
1.5 pints	100.0	100.0	99.6	99.7	[1]100.0	98.7
Synergized pyrethrum:						
1.0 quart	99.8	99.3	26.0	67.0	[1]90.7	2.9
Diatomaceous earth:						
125 pounds	98.2	96.3	54.3	95.2	[1]100.0	7.7
Untreated check	.3	1.4	1.4	8.4	[1]17.1	5.9
14 days:						
Malathion:						
1.0 pint	100.0	([2])	100.0	97.5	([3])	95.5
1.5 pints	([2])	([2])	100.0	99.7	([3])	100.0
Synergized pyrethrum:						
1.0 quart	100.0	99.4	28.4	96.5	([3])	3.7
Diatomaceous earth:						
125 pounds	100.0	100.0	81.7	99.9	([3])	46.2
Untreated check	.9	3.0	1.8	19.2	([3])	7.3

[1] Unexplained deaths in source cultures occurred by the 7th day and continued on the succeeding days; consequently little credibility should be given data from this periodic bioassay.

[2] 100-percent mortality at the 7-day reading.

[3] Reading not made.

TABLE 7.—CONFUSED FLOUR BEETLE ADULTS: *Mortality after exposure of 7 and 14 days to samples of insecticide-treated wheat*

Exposure period, insecticide, and dosage per 1,000 bushels	Mortality during sampling period of—					
	7 days	1 month	3 months	6 months	9 months	12 months
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
7 days:						
Malathion:						
1.0 pint	98.8	100.0	20.8	11.8	17.4	5.1
1.5 pints	99.4	99.7	52.6	24.2	25.8	9.7
Synergized pyrethrum:						
1.0 quart	2.6	5.4	1.2	4.8	3.2	.7
Diatomaceous earth:						
125 pounds	5.2	7.7	2.8	36.6	91.6	2.4
Untreated check	.3	2.1	2.7	4.4	1.1	3.3
14 days:						
Malathion:						
1.0 pint	100.0	97.0	36.5	42.5	40.1	8.6
1.5 pints	100.0	99.8	77.7	66.0	59.9	15.4
Synergized pyrethrum:						
1.0 quart	9.3	36.6	3.8	31.3	8.3	2.1
Diatomaceous earth:						
125 pounds	71.9	68.8	32.0	94.1	100.0	7.9
Untreated check	1.8	2.4	4.1	5.2	3.9	5.2

but its effectiveness for this insect declined rapidly after that (table 7).

The synergized pyrethrum was ineffective against the confused flour beetles.

Diatomaceous earth did not give an adequate kill of confused flour beetles with the 7-day exposures except during the 9-month period when the moisture content of the wheat was less than 10 percent. The 14-day exposures killed many more confused flour beetles than did the 7-day exposures, but satisfactory kills were obtained with the longer exposure only when the moisture content of the wheat was less than 10.80 percent. The effectiveness of this material appears to be greatly enhanced when the wheat is relatively dry. This agrees with the reports of other investigators.

TABLE 8.—*Emergence of live adult insects from 1-gallon samples of insecticide-treated wheat taken at the end of the tests*

Insecticide and dosage per 1,000 bushels	Rice weevils	Flour beetles	Flat grain beetles	Others	Total
	Number	*Number*	*Number*	*Number*	*Number*
Malathion:					
1.0 pint	747	38	9	6	800
1.5 pints	214	8	0	2	224
Synergized pyrethrum:					
1.0 quart	1,763	88	45	33	1,929
Diatomaceous earth:					
125 pounds	998	125	0	14	1,137
Untreated check	3,677	1,121	2,069	234	7,101

Insect Emergence

Wheat samples taken progressively as the bins were emptied at the end of the tests were held 60 days to record insect emergence from internal infestations. The free-moving insects, kernel bits, and frass had previously been screened out. All of the samples were infested (table 8).

Emergence of rice weevils from the samples of untreated wheat from the check bins was far greater than was expected from such heavily damaged grain. The large numbers of flour beetles and flat grain beetles emerging from the check samples were the result of larvae and eggs clinging to and in the cavities of the heavily damaged grain, and undoubtedly a certain number of flat grain beetles and saw-toothed grain beetle adults remained in the rice weevil tunnels and in other breaks in the kernel during the screening process.

The fewest insects emerged from wheat treated with malathion. The 1.5-pint dosage was much more effective than the 1.0-pint dosage, as indicated by lesser numbers of insects emerging from the grain.

A considerable number of insects emerged from the wheat treated with synergized pyrethrum and a lesser number from the wheat treated with the diatomaceous earth. Somewhat comparable numbers emerged from the wheat with the 1.0-pint dosage of malathion and with the diatomaceous earth.

Insect Damage

Various methods were used to estimate insect damage to the wheat. The percentage of kernels damaged by insects, calculated kernel weight losses, the losses in pounds per bushel, the amount of insect frass, and ratings of visible damage to the undisturbed jar samples taken when the storage period began were all recorded. Relative rankings of the treatments for their effectiveness in preventing insect damage were fairly consistent. In every test, malathion ranked first at the 1.5-pint dosage and second at the 1.0-pint dosage. The diatomaceous earth was next most effective except in the insect frass measurements. The synergized pyrethrum was the poorest treatment except that less insect frass and other fine dusts were found than in the samples of wheat from the diatomaceous earth treatment. The untreated check bin lots were by far the most heavily damaged.

When the samples taken immediately after treatment and exposed to insects in the infestation room were checked for visible damage, no infestation was apparent in the malathion-treated samples (table 9). The wheat treated with synergized pyrethrum was damaged more than wheat treated with the diatomaceous earth. The samples of untreated wheat from the check bins were all heavily damaged 8 months after storage and most samples were discarded

TABLE 9.—*Visible damage observed after various intervals in 1-gallon jar samples of wheat collected immediately after treatment and subjected to mixed populations of insects*

Insecticide and dosage per 1,000 bushels	Insect damage observed after interval of [1]—					
	4 months	6 months	8 months	10 months	12 months	16 months
	Rating	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
Malathion:						
1.0 pint	0.0	0.0	0.0	0.0	0.0	0.0
1.5 pints	.0	.0	.0	.0	.0	.0
Synergized pyrethrum:						
1.0 quart	.0	.0	1.0	1.8	2.8	[2] 4.6
Diatomaceous earth:						
125 pounds	.0	.0	.4	1.0	2.0	4.6
Untreated check	1.2	1.8	4.0	4.6	5.0	----

[1] Damage rating code: 0 = no visible infestation; 1 =slight damage as evidenced by a few insects and a small amount of insect frass; 2, 3, and 4 = ascending numbers of insects and corresponding amount of insect frass; 5 = large infestation with great amounts of insect frass and spoilage of grain.

[2] 3 samples were discarded as spoiled before the 16-month reading.

TABLE 10.—*Visible damage observed after various intervals in 1-gallon jar samples of wheat collected during binning procedures and subjected to mixed populations of insects*

Insecticide and dosage per 1,000 bushels	Insect damage observed after interval of [1]—					
	4 months	6 months	8 months	10 months	12 months	16 months
	Rating	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
Malathion:						
1.0 pint	0.0	0.0	0.0	0.0	0.2	1.2
1.5 pints	.0	.0	.0	.0	.0	.0
Synergized pyrethrum: 1.0 quart	.0	1.2	2.2	3.0	4.0	[2] 5.0
Diatomaceous earth: 125 pounds	.0	.6	1.4	1.8	2.6	[3] 4.8
Untreated check	1.2	2.4	4.8	5.0	----	----

[1] Damage rating code: 0 = no visible infestation; 1 = slight damage as evidenced by a few insects and a small amount of insect frass; 2, 3, and 4 = ascending numbers of insects and corresponding amounts of insect frass; 5 = large infestation with great amounts of insect frass and spoilage of grain.

[2] 4 samples were discarded as spoiled before the 16-month reading.

[3] 1 sample was discarded as spoiled before the 16-month reading.

before the storage period ended because of spoilage.

Samples taken a few days after treatment during the leveling of the wheat in the bins followed the same pattern, except that more damage was evident. No infestations developed in the jars containing wheat treated with the 1.5-pint dosage of malathion; however, some damage was evident in wheat with the 1.0-pint dosage (table 10). Handling made a considerable difference in the amount of damage to the wheat treated with synergized pyrethrum and, to a lesser degree, the wheat treated with the 1.0-pint dosage of malathion and with the diatomaceous earth.

The weights of dust and insect frass sifted from 1-gallon samples of wheat collected as the bins were emptied at the end of the tests also were an indication of the amount of damage inflicted by insects during the test period. Only small amounts of frass were recovered from wheat with the 1.5-pint application of malathion, which suggests that damage to wheat with this treatment was negligible (table 11). More frass was evident on wheat treated with only 1.0 pint of malathion, and more yet on wheat treated with synergized pyrethrum. The most cumulative dust in treated wheat was found in samples treated with the diatomaceous earth; however, a certain amount of this dust was undoubtedly diatomaceous earth from the original dust application. Relatively little dust was found in samples from any of the treatments when compared to the large amounts found in samples from the untreated check bins.

A significant indication of the amount of damage caused by insects is the loss of weight per bushel. External and internal feeding on the kernels by the larvae and by adult insects results in a change of density and weight per given volume of grain. Table 12 shows the changes in weight of the wheat from all treatments during the test period. No significant

TABLE 11.—*Weight of insect frass from insecticide-treated wheat*

Insecticide and dosage per 1,000 bushels	Frass weight	
	Average	Range
	Grams	*Grams*
Malathion:		
1.0 pint	3.21	1.7– 4.7
1.5 pints	.55	.3– .9
Synergized pyrethrum: 1.0 quart	5.69	2.7– 8.3
Diatomaceous earth: 125 pounds	9.11	3.2– 12.3
Untreated check	104.55	80.1–138.4

TABLE 12.—*Test weights of insecticide-treated wheat at given intervals during the test period*

Insecticide and dosage per 1,000 bushels	Weight per bushel—						Loss (−) or gain (+)	
	Before treatment	Immediately after treatment	After 3 months	After 6 months	After 9 months	After 12 months	Total	After treatment
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Malathion:								
1.0 pint	60.6	60.7	60.6	60.3	61.0	60.4	−0.2	−0.3
1.5 pints	60.6	60.5	61.0	60.4	61.1	60.6	.0	+.1
Synergized pyrethrum: 1.0 quart	60.6	60.4	60.0	58.0	58.7	58.5	−2.1	−1.9
Diatomaceous earth: 125 pounds	60.6	56.2	56.2	56.1	56.3	55.3	−5.3	−.9
Untreated check	60.6	60.7	57.6	52.4	50.7	46.3	−14.3	−14.4

losses due to insect damage occurred in wheat treated with either dosage of malathion (table 12). The weight loss of 1.9 pounds per bushel in the wheat treated with synergized pyrethrum was not as great as was indicated by the large numbers of live insects recovered from the probe samples (table 4) and by the low mortalities of the rice weevils and confused flour beetles recovered during the toxicity studies (tables 6 and 7). The application of the diatomaceous earth caused an initial weight loss in the wheat of 4.4 pounds per bushel. The dust on the kernels affected their settling and nestling, and resulted in fewer kernels per given volume. The weight loss due to insect damage in wheat treated with the diatomaceous earth was 0.9 pound per bushel.

The progressive weight loss in the untreated check wheat, which eventually amounted to nearly one-fourth of the initial weight, was in sharp contrast to the relatively small losses in any of the treatments.

Before an insect is killed by chemical or other residues, it may cause some damage to grain. Samples of 500 kernels were examined from each bin at the end of the test to record the percentage of kernels damaged by insects and to calculate kernel weight loss caused by insect feeding. Some heavily damaged kernels were lost by breaking into fragments during screening. Only 2.04 percent of the kernels were damaged in wheat treated with the 1.5-pint dosage of malathion, and a corresponding weight loss of 1.29 percent was calculated from the weights of the damaged and undamaged kernels (table 13). The other treatments were less effective in preventing damage; however, they all afforded outstanding protection in comparison to the heavy damage to the untreated check wheat, which had more than 92 percent of the kernels damaged and a calculated kernel weight loss of about 31 percent. The 1.0-pint application of malathion was more effective than the diatomaceous earth, which was in turn more effective than synergized pyrethrum.

TABLE 13.—*Kernel damage and calculated weight loss in insecticide-treated wheat after the 12-month test period*

Insecticide and dosage per 1,000 bushels	Kernels damaged	Weight loss
	Percent	*Percent*
Malathion:		
1.0 pint	4.68	2.77
1.5 pints	2.04	1.29
Synergized pyrethrum: 1.0 quart	9.36	8.26
Diatomaceous earth: 125 pounds	8.56	6.98
Untreated check	92.60	30.77

Progeny Damage

Supplementary data on progeny damage to composite samples, made from the subsamples that had been exposed to the insects in the toxicity and food preference studies, substantiated the results of the other tests. Table 14 shows ratings of the visible damage by infestations that developed in toxicity test composites 6 months after the periodic samplings. Wheat from the 1.5-pint treatments of malathion remained completely free of infestations throughout the period, and very little damage occurred to wheat from the 1.0-pint treatment. Damage to wheat treated with the synergized pyrethrum was quite pronounced, beginning with the samples taken after 3 months. Samples from the diatomaceous earth treatment showed progressively greater damage ratings as the length of the test period progressed; however, a certain amount of the fine diatomaceous earth dust was lost in the air during each of the three siftings of the subsamples and in combining the composites. Damage to the untreated check wheat was extensive.

The comparative speed of the kill of adults as shown in the toxicity test data (tables 6 and 7) undoubtedly affected the numbers of eggs deposited in the subsamples; consequently, differences in the amount of damage by progeny between the malathion and diatomaceous earth treatments might be expected.

TABLE 14.—*Visible damage by insect progeny observed in 1-quart samples of insecticide-treated wheat composited from the toxicity test subsamples*

Insecticide and dosage per 1,000 bushels	Damage observed 6 months after a sampling period of [1]—				
	1 month	3 months	6 months	9 months	12 months
	Rating	*Rating*	*Rating*	*Rating*	*Rating*
Malathion:					
1.0 pint	0.0	0.2	0.0	0.0	0.2
1.5 pints	.0	.0	.0	.0	.0
Synergized pyrethrum:					
1.0 quart	.2	4.8	1.4	2.8	3.0
Diatomaceous earth: 125 pounds	.0	.8	1.0	1.6	2.2
Untreated check	5.0	5.0	3.4	4.4	4.0

[1] Damage rating code: 0 = no visible infestation; 1 = slight damage as evidenced by a few insects and a small amount of insect frass; 2, 3, and 4 = ascending numbers of insects and corresponding amount of insect frass; 5 = large infestation with great amounts of insect frass and spoilage of grain.

FINDINGS

An objective evaluation was made in small-bin laboratory tests of the protectant properties of two dosages of malathion, and of single dosages of synergized pyrethrum and a diatomaceous earth when applied to hard red winter wheat. The following conclusions were drawn from these tests.

(1) Malathion applied at the rate of 1.5 pints of 57-percent premium-grade emulsifiable concentrate per 1,000 bushels protected wheat almost completely from insect damage for 12 months while exposed to heavy and continuous attacks by mixed populations of insects.

(2) Malathion applied at the rate of 1.0 pint was not quite as effective as at 1.5 pints but gave excellent protection.

(3) The deposits from each of the malathion treatments were ineffective in supplemental bioassay tests against confused flour beetle adults after 1 month, but remained effective against rice weevil adults for the 12-month test period.

(4) Relatively good protection resulted when wheat was treated with a diatomaceous earth at the rate of 125 pounds per 1,000 bushels, in comparison with the heavily damaged untreated wheat.

(5) The synergized pyrethrum and the diatomaceous earth treatments rendered the wheat about equally repellant to rice weevils, but no distinct repellant nor attractant action was evident in either malathion treatment.

(6) The diatomaceous earth was more effective, especially against the adult confused flour beetles, when the moisture content of the wheat was about 10.5 percent or less.

(7) The synergized pyrethrum emulsifiable concentrate applied at the rate of 1 quart per 1,000 bushels gave results generally comparable to the diatomaceous earth treatment, the latter being slightly better in most respects.

(8) Malathion at both dosages gave faster and greater kills of rice weevils than the diatomaceous earth in the toxicity studies. It is reasonable to assume that large numbers of eggs could be deposited during the longer periods required by the diatomaceous earth for kill, as evidenced by the numbers of insects recovered in the emergence test.

(9) The diatomaceous earth killed more confused flour beetles in bioassay tests than did either dosage of malathion, when the wheat contained about 10.5 percent moisture or less. The synergized pyrethrum was ineffective against this insect.

(10) An overall appraisal of the visible damage to samples retained in glass jars—damage to the kernels, kernel weight losses, losses in weight per bushel, and numbers of insects emerging from samples taken as the test ended—shows clearly that the 1.5-pint dosage of malathion was the most effective treatment, followed in order of effectiveness by the 1.0-pint dosage of malathion, the diatomaceous earth, and the synergized pyrethrum.

(11) The counts of live insects in probe samples show comparable results for the 1.5-pint dosage of malathion and the diatomaceous earth during the latter part of the test period. The 1.0-pint dosage of malathion shows greater insect populations in the bins, the synergized pyrethrum still greater, but neither shows nearly as much as the untreated check bins.